

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Tmx 71363
**NONTHERMAL GALACTIC EMISSION
BELOW 10 MHz**

(NASA-TM-X-71363) NONTHERMAL GALACTIC
EMISSION BELOW 10 MHZ (NASA) 33 p
HC A03/MF A01

CSSL 03B

N77-31067

G3/93 Unclass
42860

**JAMES C. NOVACO
LARRY W. BROWN**

JULY 1977



GSFC

**— GODDARD SPACE FLIGHT CENTER —
GREENBELT, MARYLAND**

NONTHERMAL GALACTIC EMISSION BELOW 10 MHz

James C. Novaco
Larry W. Brown
Infrared and Radio Astronomy Branch
Laboratory for Extraterrestrial Physics
Goddard Space Flight Center
Greenbelt, Maryland 20771

Abstract

The Radio Astronomy Explorer-2 (RAE-2) satellite has provided new measurements of the nonthermal galactic radio emission at frequencies below 10 MHz. Measurements of the emission spectra are presented for the center, anticenter, north polar, and south polar directions at 22 frequencies between 0.25 and 9.18 MHz. Survey maps of the spatial distribution of the observed low frequency galactic emission at 1.31, 2.20, 3.93, 4.70, 6.55, and 9.18 MHz are presented. The observations were obtained with the 229-meter traveling-wave V-antenna on this lunar orbiting spacecraft. The improved frequency coverage offers additional insights into structure of the local galactic neighborhood.

I. INTRODUCTION

The Radio Astronomy Explorer-2 (RAE-2) satellite is the second in a series launched for the exclusive purpose of making low frequency radio astronomical measurements of the planets, of the Sun, and of our Galaxy. In this paper, the investigations of the nonthermal galactic radiation with data from RAE-2 are presented. Among the major unexpected results from the RAE-1 satellite were the very common and often extremely intense nonthermal radio emissions from the Earth (Herman et al., 1973). Although these emissions are of great interest in themselves, they seriously interfered with attempts to measure the nonthermal galactic radiation. Therefore, the RAE-2 was modified to be operated in lunar orbit instead of in Earth orbit like RAE-1. The increased distance from the Earth would not only significantly reduce the contamination caused by the terrestrial emissions, but the resulting lunar occultations of the Earth would completely eliminate the emissions over a portion of the observing time. Improvements were made to the receiver systems to take advantage of the new environment and to utilize the experience gained from the performance of the RAE-1 instruments.

The RAE-2, launched on 10 June 1973, was placed into an 1100 km circular lunar orbit five days later. The orbit has a period of 222 minutes and an inclination of 59° to the lunar equator. Sky coverage is obtained through a combination of orbital scans and precession of the orbital plane of $-0.14^{\circ}/\text{day}$ along the lunar equator.

This results in a precession of approximately 4 hours in right ascension and 15° in declination per year. Shielding from terrestrial kilometric radiation by earth occultations occur approximately half of every two week period and may last up to 20% of the orbital period. At other times, the measurements of the galactic radiation are still limited somewhat by the ability to discriminate against contaminating signals.

II. INSTRUMENTATION

The RAE-2 spacecraft is a dedicated low frequency radio astronomy observatory. A complete description of the spacecraft is given by Alexander et al. (1975). The antenna systems consist of two traveling-wave V-antennas deployed from the spacecraft to form an X-configuration, separated by a 37-m dipole antenna deployed along the minor axis of symmetry. Gravity gradient forces are used to stabilize the spacecraft so that one V-antenna always points toward the lunar surface and the other points outward. This outward directed antenna is used to scan the celestial sphere and make measurements of the galactic radiation. The antenna is 229m in length with an equivalent apex angle of 35° . The radiation properties of this antenna have been calculated by Sayre (1974) showing that the solid angle of the main lobe varies from a steradian near 10 MHz, to approximately hemispheric near 1 MHz and nearly dipolar at the lowest frequencies (Table 1, columns 2 and 3). Measurements of the radiation pattern made by scanning the Sun and Earth have confirmed this theoretical work.

The receiving system on the RAE-2 is similar to that used on RAE-1 (Weber et al., 1971). Two types of radiometers are used to measure the galactic radiation. The first type using the Ryle-Vonberg feedback concept, provides measurements which are insensitive to gain and bandwidth changes, and thus gives stability over the many months required to map the galactic radiation. The Ryle-Vonberg (RV) radiometer operates at nine discrete frequencies (Table 1) from 0.450 to 9.18 MHz in a sequence which requires 138 seconds to complete. It has an effective bandwidth of 40 kHz and post-detection time constant of 0.1 seconds. A coarse output channel is obtained from the integrated servo-loop error signal and a fine output channel is obtained from the more accurate measurement of the noise-source output required to match the antenna signal. The time constant of the fine channel is 0.5 seconds. The fine output channel was used in the analysis of the galactic radiation for the RAE-2 data resulting in an improvement over the RAE-1 data where only the coarse output channel was available.

The second type radiometer is a total power receiver covering the frequency range 0.025 MHz to 13.1 MHz in 32 discrete steps of which 18 have been used in the measurement of the galactic radiation (Table 1). A complete cycle through the 32 steps requires 8 seconds. This burst receiver (BR) radiometer has an effective bandwidth of 20 kHz and a post-detection time constant of 6 milliseconds.

The receiving system was calibrated in the laboratory using improved techniques similar to those employed for the RAE-1 (Weber et al., 1971) and the Interplanetary Monitoring Platform-6 (IMP-6)

spacecraft (Brown, 1973). Flight data have indicated good receiver performance with gain variations not exceeding 10% per year.

III. DATA REDUCTION

The principal problem associated with the measurements of the nonthermal galactic radiation is the contamination of the data due to emissions from the Earth, Sun, and other sources such as Jupiter and Saturn (Brown, 1974a, 1974b, 1975). This emission is primarily sporadic and will be superimposed on the steady underlying signal. The assumption is made that the minimum emission observed during quiet periods is the nonthermal galactic radiation. The validity of this assumption is supported by observing those lunar occultation periods when the major sources of contamination are shielded. A second problem arises from changes in instrument performance especially in terms of long-term drifts due to aging of the receivers. Data handling procedures followed those developed by Alexander and Novaco (1974).

The problem of editing data to remove the contaminating sources was approached in several steps. Since the Earth is the dominant emission source, the data were examined for quiet periods free from Earth radiation. Most of the Earth's emission, particularly that above 1 MHz, occurs when the Moon, at full phase, is above the nighttime ionosphere which allows man-made and natural radio noise to penetrate to the spacecraft (Herman et al., 1973, Alexander et al., 1975, Gurnett, 1974, Alexander and Kaiser, 1976). To eliminate most of the

Earth emission only the twelve day time period centered on the new Moon phase was used. The data were rejected from the new Moon periods if a visual examination showed evidence of solar activity or additional Earth radiation.

Even with the elimination of these data, the data base still contained more than enough observations to provide extremely reliable measurements. Spectra for four cardinal directions (north galactic pole, south galactic pole, center, and anticenter) of the Galaxy were obtained from ten new Moon periods or about 120 days of observation. Contour maps of the observed parts of the Galaxy were constructed from these data and an additional 224 days of data.

During the periods when the RAE-2 was shadowed from the Sun by the lunar disk, thermal gradients caused large antenna boom tip motions relative to the spacecraft body. This motion creates changes in the antenna impedance that appear as a 50 minute oscillation in the observed data particularly at frequencies near the antenna resonances. None of these data was used in the spectral data analysis; however, it was necessary to use some of the less affected data to provide continuous coverage in the galactic mapping. Careful comparison with nearby data groups not affected by the thermal problems showed that the data were entirely consistent with those obtained outside this period. The standard deviation was less than 4% higher for the accepted shadow data than for the unaffected portions of the map.

Since the remaining interference is characterized by individual bursts of emission for short time intervals, these sources could be removed from the data statistically.

First, the average galactic radiation level was estimated by visual examination over four day periods. Then, an initial amplitude filter eliminated any observed antenna temperature more than ± 2 db above this average level. The width of this filter was chosen by examining the maximum contrast observed on RAE-1 and ground-based low frequency surveys that were smoothed to the resolution of the antenna. The average was further refined as the background measurement improved through an iterative process. Usually no significant changes were produced after two iterations.

Due to the slow scan rate and low resolution, galactic features produce a slow variation in the observed signal as opposed to abrupt onsets of the contaminating emissions. The average signal levels in adjacent 10 minute intervals were compared and the latter interval was removed from the data base if the average exceeded a 1.5 db shift from the former. This had the effect of removing the solar and terrestrial bursts, particularly the onset or decay, missed with the initial filtering, as well as the telemetry anomalies which occasionally occur.

Data passing through these filters were sorted by position into $5^\circ \times 5^\circ$ bins of galactic longitude and latitude. As measurements were added, the average antenna temperature and its standard deviation was calculated for each bin. Data points falling more than four standard deviations (4σ) from the average were deleted and the statistics

recomputed. This process was repeated until all the data retained were within the 4σ range. If the number of data points in any bin fell below 10 without convergence, the data were eliminated from the analysis. After merging all the four day groups, the final contours of the galactic maps were constructed.

The merged data cover a time span of $2\frac{3}{4}$ years. Although it was shown that there were no short term receiver problems, long term drifts over this period of time had to be removed from the data by normalizing the average emission for each four day group to the orbital average before merging with other groups. It was shown by Alexander and Novaco (1974) with RAE-1 data that at these low frequencies and with such large antenna patterns the average galactic emission does not significantly vary over an orbit of the spacecraft regardless of the orientation of the antenna. While this prevented any direct determination of the absolute observed galactic fluxes, the difficulty in computing the absolute power received by the V-antenna required an indirect method. The absolute fluxes were calculated by comparing the normalized averages to the average galactic emission observed by the IMP-6 spacecraft (Brown, 1973) and extrapolated above 2.6 MHz. The IMP-6 spectra were obtained with a short dipole antenna whose properties were well understood. The spectra represent a reliable calibration of the average absolute flux emitted by the Galaxy and should provide a standard for the RAE-2 normalized spectra.

The resultant spectra of the four cardinal directions, center, anticenter, north polar, and south polar galactic regions, are presented in Figures 1 and 2. The error bars shown are representative of the 1-4 MHz frequency range. The galactic maps for the frequencies 9.18, 6.55, 4.70, 3.93, 2.20 and 1.31 MHz are shown in Figures 3 through 8 respectively. The contours are given in units of absolute brightness temperature as determined from comparison of the RAE-2 average temperature with the galactic spectrum measured by IMP-6.

IV. ERRORS

The measurement errors encountered in the observation can be estimated and compared to those obtained from the statistical analysis of the data. Since the average galactic emission has been normalized and then scaled using the IMP-6 absolute calibration as the standard, the measurement errors arise only from random variations encountered in the RAE-2 system calibration and not from any systematic trends.

The relative calibration error for the RAE-2 system is approximately 4% for the BR receivers and 3% for the RV receivers. Other errors arise from the instabilities in the receivers. Based on the noise figure of the pre-amplifiers and the bandwidths and time constants of the system, variations of 10% for the BR receivers and 4% for the RV receivers should be expected. The short term instability for both type receivers appears to be less than 1%, while the long term drift could not be corrected to better than 7% for both. The total relative instrumental error is estimated then to be 14% of the RV system and 9% for the BR system.

Table 1 lists the observational errors actually observed. In this table, column (1) list the frequencies used for the two receivers. Columns (4) and (7), give the relative error derived from the analysis of the data presented here. Columns (5) and (8), give the absolute error for the average galactic emission observed by IMP-6 (Brown, 1973). Finally, columns (6) and (9), give the total error which is the square root of the sums of the squares of the relative and absolute errors for each receiver. Frequencies near antenna resonance suffer larger errors and these are noted with a (Λ). Those RV receiver frequencies used to produce maps of the galactic radiation are noted with a (*). The relative errors compare favorably with the instrumental errors, especially when the frequency dependence of the errors is taken into account.

At the time the RAE-2 was scanning the anticenter, the Sun, which was in this region of the sky, was particularly active. Even with filtering, its effect was noticable between 0.6 and 1.5 MHz. The data above 1.5 MHz and below 0.6 MHz indicate that in this frequency range, the spectra observed for the center and anticenter regions are probably in agreement. Based on this agreement, the amount of solar contamination was estimated and removed from the spectra. Naturally the error in this portion of the spectra is somewhat larger.

In addition, some portions of the 2.2 MHz map are affected by the 50-minute oscillations resulting from solar shadowing of the antenna. At this frequency the oscillations cause an increase in the standard deviation of less than 4%.

At 9.18 MHz the data are still contaminated by man-made and natural radio noise which could penetrate the terrestrial ionosphere. At this end of the RAE-2 frequency range, the ionosphere is much more transparent to electromagnetic radiation for a larger portion of time. The consequence of this is the loss of a large percentage of the data with the resulting sparsely covered map. The Penticton and Tasmanian 10 MHz surveys (Purton et al., 1970; Hamilton and Haynes, 1968) were smoothed to the equivalent RAE-2 antenna beamwidth and used to verify the manner in which the contours of the 9.18 MHz bridged the data gaps. The resulting map is not as reliable as the other maps presented, but the increase in the error should be less than 20%.

V. DISCUSSION

At these low frequencies, the galactic radiation is composed of synchrotron emission from cosmic ray electrons interacting with the interstellar magnetic field. While this radiation persists throughout the Galaxy, variations exist which are associated with the strength of the magnetic field and the concentration of cosmic ray electrons due to spiral arms, supernova remnants, and other irregularities. As the observing frequency is lowered, the emission that is observed is produced more by lower energy cosmic ray electrons and in regions of weaker magnetic field. In addition free-free absorption by the thermal electrons in the ionized component of the interstellar medium becomes increasingly important. Even regions where the thermal electron density is quite low are efficient absorbers of this low frequency radiation.

Observing over a significant range of these low frequencies results in sampling the interstellar medium over a range of opacities.

This is well illustrated in the spectra of the galactic center and anticenter directions presented in Figure 1. At 10 MHz the spectra are dominated by the large scale galactic structure. The central part of the Galaxy is brighter because both the pathlength and the emissivity are greater in the inner parts of the Galaxy. At lower observing frequencies, free-free absorption reduces this pathlength difference so that the observed intensities in the two directions approach each other. The pathlengths for the lowest frequencies are well within the local solar neighborhood (at 0.3 MHz about 10 to 50 parsecs), and with the large beamwidths of the RAE-2, the average properties are the same in both directions.

The galactic polar regions (Figure 2) show a different picture. At high frequencies, the pathlength extends beyond the galactic boundary in both directions, and the observed brightness includes emission from the extragalactic background (Clark et al., 1970). Near 10 MHz the intensities of the north and south polar regions are nearly identical, showing very little difference in the average local properties above and below the galactic plane. However, between 1 and 4 MHz the south polar spectrum is slightly lower than that in the north. Using a model of the local galactic region which was developed from the interpretation of the RAE-1 data (Novaco and Vandenberg, 1972), this difference could be reproduced by increasing the absorption in

the cloud medium in a two component model. The observed difference was reproduced either by decreasing the temperature by a factor of 2 or by increasing the cloud diameters by a factor of 4 which is the same as introducing four times as many clouds. Heiles (1975) has shown that the Sun is not located symmetrically with respect to the magnetoactive interstellar medium, but is north of the line of symmetry. This increases the pathlength toward the south and causes the difference in the polar spectra.

At the lowest observing frequencies the intensities toward the four cardinal directions are equal. Since the pathlength is short and the antenna pattern large, it would not be unrealistic for the local structure to appear isotropic.

The effect of observing frequency on the observed regions of the interstellar medium can be illustrated further by examining the contour maps of the observed emission (Figures 3 thru 8). The maps are characterized at most of the frequencies by a region of high observed emission that envelopes an area toward the galactic center and a region of low observed emission that extends well south of the galactic equator at a galactic longitude of approximately 240° . At the higher frequencies, the large scale galactic structure dominates and the map contours tend to lie parallel to the galactic equator. At the lower frequencies, where the pathlength is more restricted, the map contours become normal to the galactic equator.

Centered at or greater than longitude 220° is an extensive region of low observed brightness situated in an area where several factors

contribute to the lack of emission. First, this region spans an area which shows a minimum of emission as observed in higher frequency ground-based surveys (eg. Purton et al., 1970; Hamilton and Haynes, 1968). The observations suggest that these areas either contain a lower magnetic field strength, or a lower concentration of cosmic ray electrons than other parts of the Galaxy. Either condition or combination of them could produce the observed minimum emission contours of the low frequency RAE-2 maps. A part of this area contains particularly large structures with high concentrations of ionized material (Sivan, 1974). A great deal of this material is contained in two large features, the Gum Nebula ($l \sim 265^\circ$, $b \sim -5^\circ$) and the I Orion Association ($l \sim 205^\circ$, $b \sim -15^\circ$). At these low frequencies, this material is a highly efficient absorber, greatly contributing to the low brightness.

In the higher frequency RAE-2 maps where the path extends deeply into the inner parts of the Galaxy, the high emission region is a blend of radiation from the North Galactic Spur and the inner galactic regions. At the highest frequencies the radiation from the inner parts of the Galaxy is the dominant source shaping the contours of the maximum observed emission. The maps at lower frequencies show this area moving toward galactic longitudes nearer 40° . This is a result of a smaller contribution from the inner galactic regions due to shorter pathlengths and an increasing prominence of the Spur, particularly where the Spur crosses the galactic plane. As the frequency is decreased, the nonthermal radiation becomes more

absorbed by ionized material and more distant parts of the Galaxy will contribute little, if any, to the total observed radiation, hence, the Spur will be a dominant feature of the maps at these frequencies.

The 6.55 and 3.93 MHz maps (Figures 4 and 6) agree well with those of RAE-1 (Alexander and Novaco, 1974) where the RAE-1 data are reliable. The average brightness measured at the South Galactic Pole is the same for each survey although the RAE-2 maps indicate a gradient across the region. The high brightness region at longitudes $20-60^\circ$ exist in both surveys but is more extended with a slightly different centroid in the RAE-2 maps. The low brightness region at $l = 40^\circ$, $b = -30^\circ$ in the 3.93 MHz RAE-1 maps was not reproduced by RAE-2; however, a featureless region at $l = 240^\circ$, $b = -40^\circ$ appears as a low brightness region in the RAE-2 maps. These discrepancies occur in regions of the sky where the RAE-2 data are much more reliable than that of RAE-1.

The 4.7 MHz map contains a small area in common with the ground based surveys of Ellis and Hamilton (1966). The agreement between the surveys is excellent if their survey is convolved with the RAE-2 antenna pattern; however, the gradient observed across the South Galactic Pole is not present in their survey. The intensity scales of the surveys agree to within a factor of two. This is excellent agreement given the uncertainties in the effective collecting area and solid angle of the V-antenna of RAE-2.

At 2.20 MHz the center of the maximum emission lies south of the plane at longitude $\sim 40^\circ$. The Cetus Arc, another galactic loop, has a strong observed emission ridge in this area ($l \sim 45^\circ$, $b \sim -40^\circ$) and influences the location of the observed maximum by blending with the North Galactic Spur. This is supported by the movement with decreasing frequency of the observed maximum away from the direction of the Galactic Center to ever increasing longitude as well as south of the plane. This could imply that the emission from the Cetus Arc is a more dominant feature at a lower observing frequency than the North Galactic Spur.

It is intriguing to speculate on the possible implications of this observation. The simplest picture would be that the emission dominance of the Cetus Arc at a lower frequency than that for the North Galactic Spur implies that the Spur lies at a greater distance from the Sun. However, for this to be correct, the absorption properties of the instellar medium in the directions of these loops would have to be nearly identical and the loops themselves must have nearly identical spectra. This observation could lead to an estimate of the pathlength over which the galactic emission is observed at these frequencies.

In an extensive investigation of the observational evidence on the galactic loops, Berkhuijsen et al. (1971) concluded that they are supernova remnants and that several of these loops should lie within a few hundred parsecs of the Sun. Support for the supernova hypothesis has come from the detection of diffuse nebulosities in the

North Galactic Spur and the Cetus Arc (Haslam et al., 1971; Berkhuijsen, 1971) and by the detection of soft x-rays from the Spur (Bunner et al., 1972; Cruddace et al., 1976). Model calculations supported by other evidence were used by Berkhuijsen (1973) to estimate the surface brightness and distance of the loops. The center of the Spur was estimated to be 130 ± 75 parsecs from the Sun. The Cetus Arc was 110 ± 40 parsecs with the same spectral index (2.7 ± 0.2) and a slightly lower surface brightness than the Spur. In a general way, this relationship between the two loops appears to be reflected in the galactic maps of the RAE-2 observations. However, previous attempts to construct emission models for the low frequency galactic radiation (Clark et al., 1970; Brown, 1973; Novaco and Vandenberg, 1972) have indicated a pathlength which is slightly longer than that indicated above, although still of the order of hundreds of parsecs. Optical polarization measurements (Mathewson and Ford, 1970) tend to support the smaller pathlength, as the effects of the loops on the polarization of starlight are first observable for stars at distances of 50 to 200 parsecs. If the supernova origin of the loops is accepted, then the previous galactic modeling must be reconsidered.

The 2.2 MHz map contains a region bounded by longitudes 320 to 30° and latitudes $+50$ to -90° which is common to a 2.1 MHz ground based survey of Reber (1968). Again the agreement between surveys is excellent when his survey is convolved with the RAE-2 antenna pattern. Although the high brightness region at $l = 40^\circ$, $b = 10^\circ$ in the RAE-2 map is outside

the common boundaries, the contours of Reber's survey near the boundary are consistent with such a region. Similarly the low brightness region of RAE-2 at $l \geq 240^\circ$ appears to be supported by the contours near this boundary. Again a discrepancy occurs near the South Galactic Pole where the ground based survey is nearly featureless as opposed to the gradient appearing in the RAE-2 map. The intensity scales of the surveys agree to within a factor of four, which is reasonable given the uncertainties in the effective collecting area and solid angle of the V-antenna of RAE-2 and the uncertainty in correcting the ionosphere at 2 MHz.

The 1.31 MHz map indicates a complete change in the observed radiation. The center of the maximum emission area is again along the galactic plane but near a longitude of approximately 100° . Neither the Cetus Arc nor the North Galactic Spur is visible indicating that the pathlength is now shorter than the distances to the loops (~ 110 pc). Thus the radiation is confined to a very localized region well within the local spiral arm. Then, the 1.31 MHz map is a reflection of the properties of the local interstellar medium and its magnetic field in the immediate neighborhood of the Sun.

Most of the knowledge of the local galactic magnetic field comes from the measurement of Faraday rotation of linearly polarized radio sources (Wright, 1973; Whiteoak, 1974; Gardner et al., 1969). Mathewson and Nichols (1968) considered both optical and radio data, and postulated the existence of a large scale, systematic longitudinal local field directed toward $l \sim 90^\circ$, on which was superimposed a local

perturbation. The longitudinal field has been verified by a number of investigations (Wright, 1973, Manchester 1974, Guelin, 1974) with typical results yielding a longitudinal field of $2.5 \mu\text{G}$ directed toward $l \sim 94^\circ$ and a large-scale fluctuating component 50% larger than the longitudinal one with a correlation length of several hundred parsecs.

The RAE-2 galactic map at 1.31 MHz reflects these results. The path over which this galactic emission is observed appears to be slightly less than the correlation length of the fluctuating component of the local field. One would expect a complete change in the spatial pattern of the observed emission if the shorter path is dominated by regions with similar magnetic properties and orientations. Although the 1.31 MHz map contains no data at $l = 94^\circ$, the observed intensity contours about this area suggest that the center of the maximum emission must fall near the direction of the longitudinal field component. The map contours would seem to outline the structure of the local galactic field. Unfortunately the RAE-2 survey does not cover the area opposite the direction of the longitudinal field. This area should have a similar structure unless the Gum Nebula and I Orion Association reduce the average correlation length.

In summary, the Radio Astronomy Explorer-2 has provided new measurements of the nonthermal galactic radiation below 10 MHz. Spectra for the directions toward the Galactic Center, Anticenter, and North and South Galactic Poles have been presented and discussed.

Between 1 and 4 MHz, the emission in the south polar region is less than the northern region. This is probably caused by the longer path-lengths towards the southern region. At the lowest frequencies, all four spectra are nearly identical, indicating that the paths are restricted to an isotropic region in the solar neighborhood.

Maps of the spatial distribution are presented at 6 frequencies. While the contrast in the maps is low because of the large beamwidths, the North Galactic Spur and the Cetus Arc are seen in emission, and the Gum Nebula and I Orion Association are seen in absorption. At 1.31 MHz the radiation path is restricted to the solar neighborhood. The only dominant feature observed is probably related to the local magnetic field.

ACKNOWLEDGEMENTS

We gratefully acknowledge our many colleagues who have helped build and operate this satellite. We wish to thank P. Harper for her capable help in the data processing. We also wish to acknowledge the help of Drs. W.C. Erickson, F.J. Kerr, A.J. Klimas, R.G. Stone, Mr. J.K. Alexander and Ms. H. Malitson for their critical readings of this manuscript and their helpful suggestions.

- Alexander, J.K. and Novaco, J.C., 1974, A.J., 79, 777.
- Alexander, J.K. and Kaiser, M.L., 1976 JGR, 81, 5948.
- Alexander, J.K., Kaiser, M.L., Novaco, J.C., Grena, F.R. and Weber, R.R.,
1975, Astron. & Astrophys., 40, 365.
- Berkhuijsen, E.M., 1971, Astron. & Astrophys., 14, 359.
_____, 1973, ibid, 24, 143.
- Berkhuijsen, E.M., Haslam, C.G.T., and Salter, C.J., 1971, Astron. &
Astrophys., 14, 252.
- Brown, L.W., 1973, Ap. J., 180, 359.
_____, 1974a, ibid, 192, 547.
_____, 1974b, Ap.J. (Letters), 194, L159.
_____, 1975, ibid, 198, L89.
- Bunner, A.N., Coleman, P.L., Kraushaar, W.L., and McCammon, O., 1972,
Ap. J. (Letters), 172, L67.
- Clark, T.A., Brown, L.W., and Alexander, J.K., 1970, Nature, 228, 648.
- Cruddace, R.G., Friedman, H., Fritz, G., and Shulman, S., 1976, Ap. J.
207, 888.
- Ellis, G.R.A. and Hamilton, P.A., 1966, Ap. J., 143, 227.
- Gardner, F.F., Morris, D., Whiteoak, J.B., 1969, Aust. J. Phys.,
22, 79.
- Guélin, M., 1974, IAU Symposium No. 60, Galactic Radio Astronomy, ed.
F.J. Kerr and S.C. Simonson, III., p. 51, Dordrecht: Reidel.
- Gurnett, D.A., 1974, J. Geophys. Res., 79, 4227.
- Hamilton, J.R. and Haynes, R.F., 1968, Aust. J. Phys. 21, 895.

- Haslam, C.G.T., Kahn, F.D. and Meabum, J., 1971, Astron. & Astrophys., 12, 388.
- Haslam, C.G.T., Quigley, M.J.S., Salter, C.J., 1970, Mon. Not. R. Ast. Soc., 147, 405.
- Heiles, C., 1975, Ap. J., 204, 379.
- Herman, J.R., Caruso, J.A., Stone, R.G., 1973, Planet. Space Sci., 21, 443.
- Manchester, R.N., 1974, Ap. J., 188, 637.
- Mathewson, D.S. and Ford, V.L., 1970, Mem. R. Astr. Soc., 74, 139.
- Mathewson, D.S. and Nicholls, D.C., 1968, Ap. J. (Letters), 154, L11.
- Novaco, J.C. and Vandenberg, N.R., 1972, Goddard Space Flight Center X-693-72-8.
- Purton, C.R., Caswell, J.L., and Bridle, A.H., 1970, Meeting of the Ast. Soc. Pacific (June).
- Reber, G. (1968), J. Franklin Inst., 285, 1.
- Salter, C.J., 1970, Ph.D. Thesis, Manchester University.
- Sayre, E.P., 1974, Final Report, NASA Contract NAS 5-24007, AVSD-0144-74-CR.
- Sivan, J.P., 1974, Astron. & Astrophys. Suppl., 16, 163.
- Weber, R.R., Alexander, J.A., and Stone, R.G., 1971, Radio Science, 6, 1085.
- Whiteoak, J.B., IAU Symposium No. 60, Galactic Radio Astronomy, ed. F.J. Kerr and S.C. Simonson, III., p. 137, Dordrecht: Reidel.
- Wright, W.E., 1973, Ph.D. Thesis, California Institute of Technology.

TABLE 1
OBSERVATION SUMMARY OF ERRORS

Freq. (MHz) (1)	BR Receiver			RV Receiver				
	Half-Power E-Plane (2)	Points H-Plane (3)	Relative Error (4)	IMP-6 Error (5)	Total Error (6)	Relative Error (7)	IMP-6 Error (8)	Total Error (9)
9.18	39°	61°	15%	12%	19%	16%	12%	20%*
6.55	27	55	13	12	18	8	12	15*
4.70	70	80	13	12	18	8	12	15*
3.93	53	63	10	12	16	8	12	15*
^ 2.80	97	84	10	12	16			
^ 2.20	125	93	14	12	18	7	12	14*
1.85	140	105	14	11	18			
^ 1.45	160	115	16	11	19			
1.31	175†	120†				6	11	13*
^ 1.27	180	125	14	11	18			
1.03	210	140	14	10	17			
0.900	215†	145†				8	11	14
0.870	220	150	13	10	16			
^ 0.737	235†	155†	19	11	22			
0.700	240†	155†				8	12	15
0.600	250†	155†	19	13	23			
0.475	265†	160†	23	14	27			
0.450	270†	160†				17	14	22
0.425	275†	160†	14	14	20			
^ 0.360	285†	165†	20	21	29			
0.292	295†	170†	18	26	32			
0.250	300†	170†	33	36	49			

^ Frequencies near antenna resonance

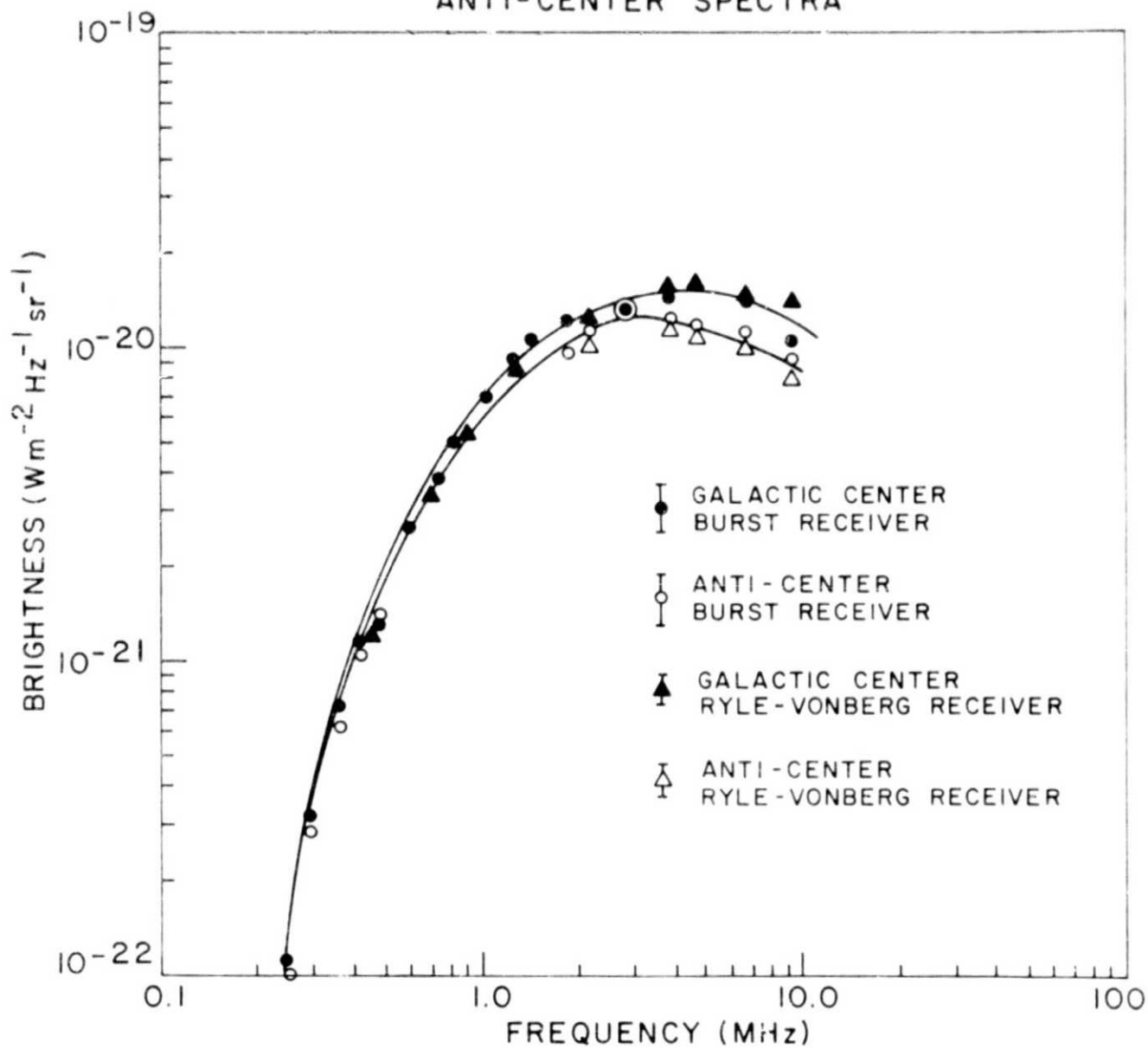
*Receiver and frequency used in galactic maps.

†Estimated values

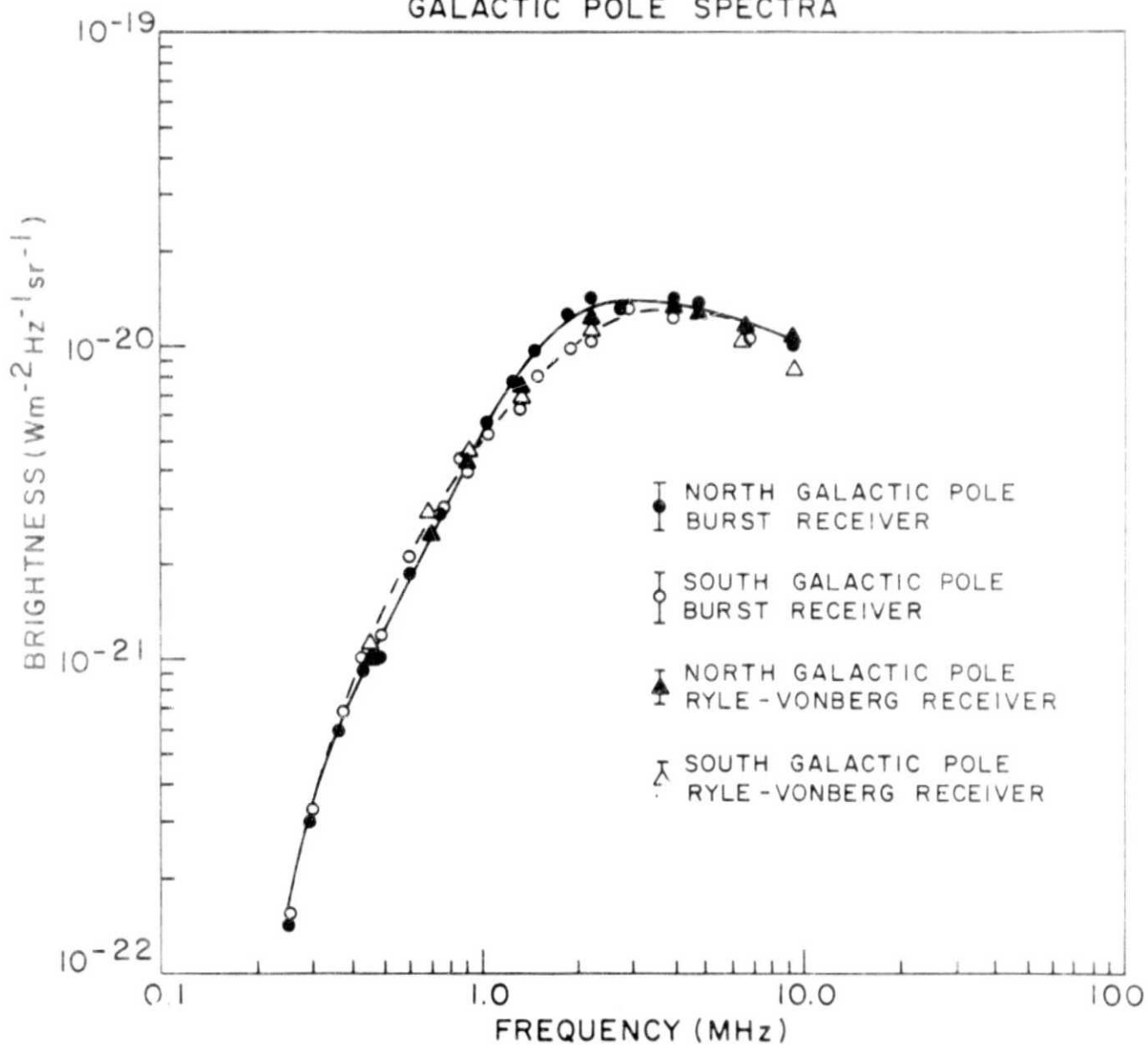
LIST OF FIGURES

- Figure 1. Spectra of the nonthermal emission as seen by RAE-2 in the galactic center and anticenter directions. The error bars shown are representative of the 1-4 MHz range.
- Figure 2. Spectra of the nonthermal emission as seen by RAE-2 in the galactic north and south polar directions. The error bars shown are representative of the 1-4 MHz range.
- Figure 3. Contour map in galactic coordinates of the nonthermal emission observed by RAE-2 at 9.18 MHz.
- Figure 4. Contour map in galactic coordinates of the nonthermal emission observed by RAE-2 at 6.55 MHz.
- Figure 5. Contour map in galactic coordinates of the nonthermal emission observed by RAE-2 at 4.70 MHz.
- Figure 6. Contour map in galactic coordinates of the nonthermal emission observed by RAE-2 at 3.93 MHz.
- Figure 7. Contour map in galactic coordinates of the nonthermal emission observed by RAE-2 at 2.20 MHz.
- Figure 8. Contour map in galactic coordinates of the nonthermal emission observed by RAE-2 at 1.31 MHz.

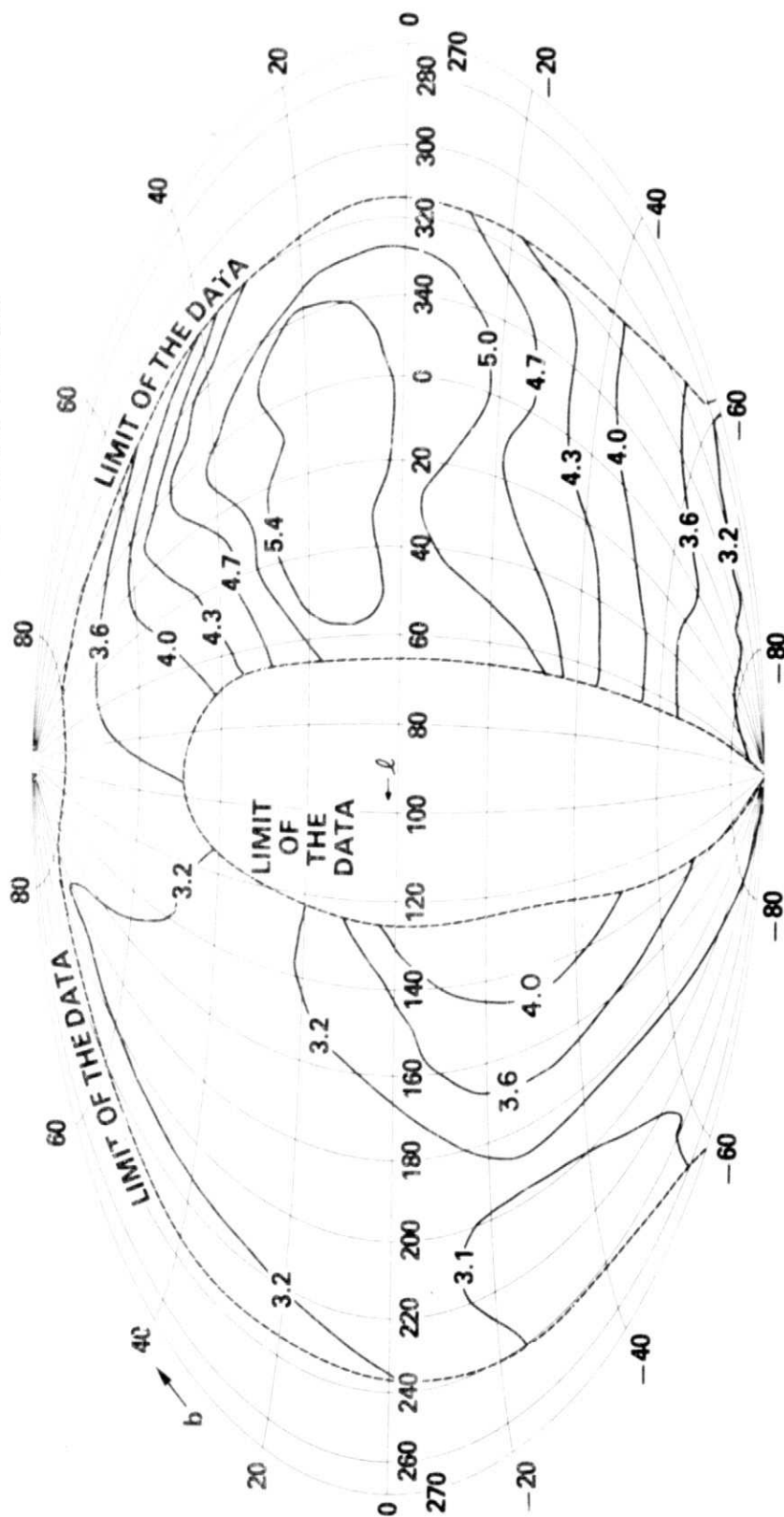
GALACTIC CENTER AND ANTI-CENTER SPECTRA



NORTH AND SOUTH GALACTIC POLE SPECTRA

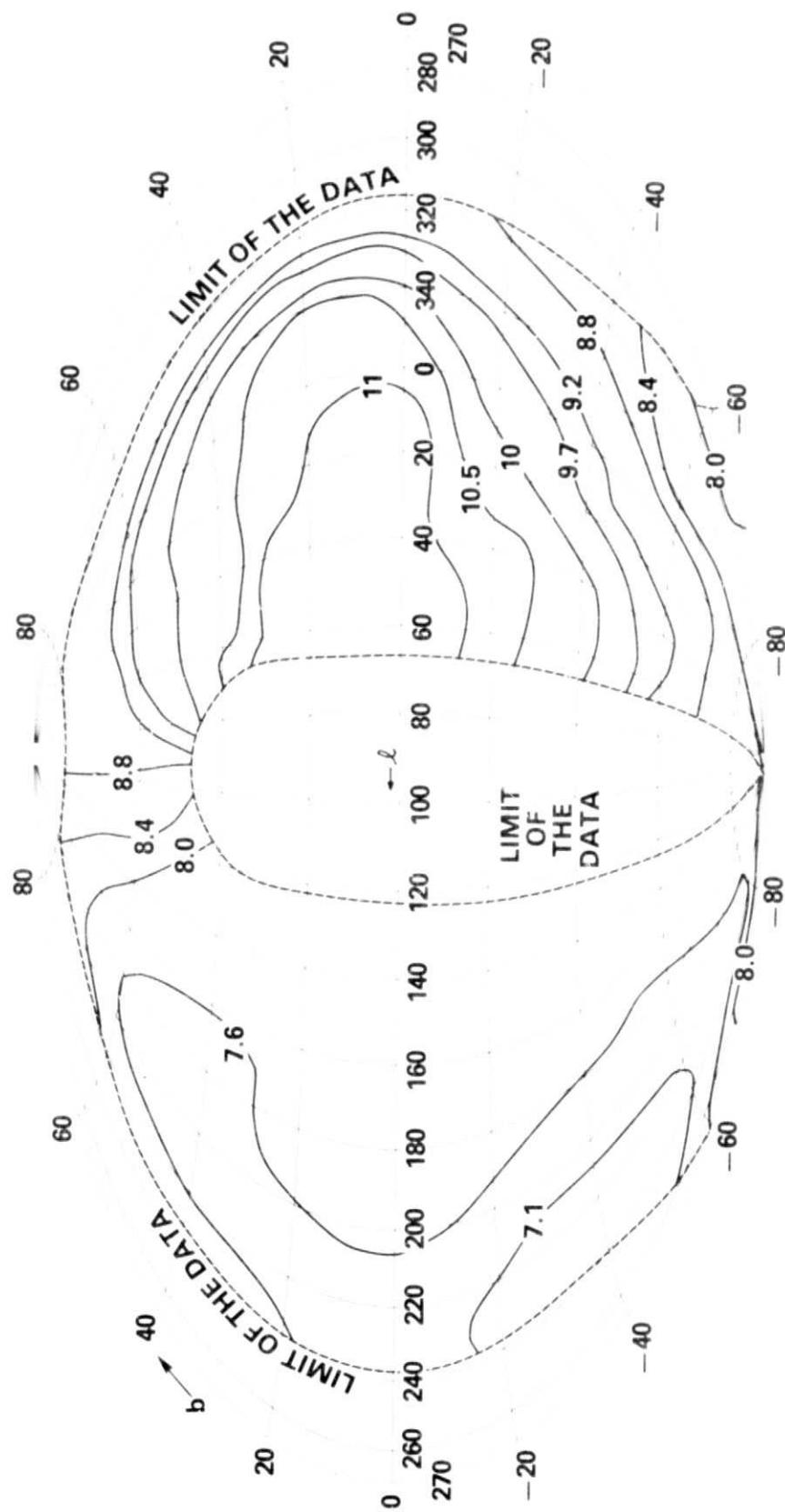


GALACTIC BACKGROUND AT 9.18 MHz



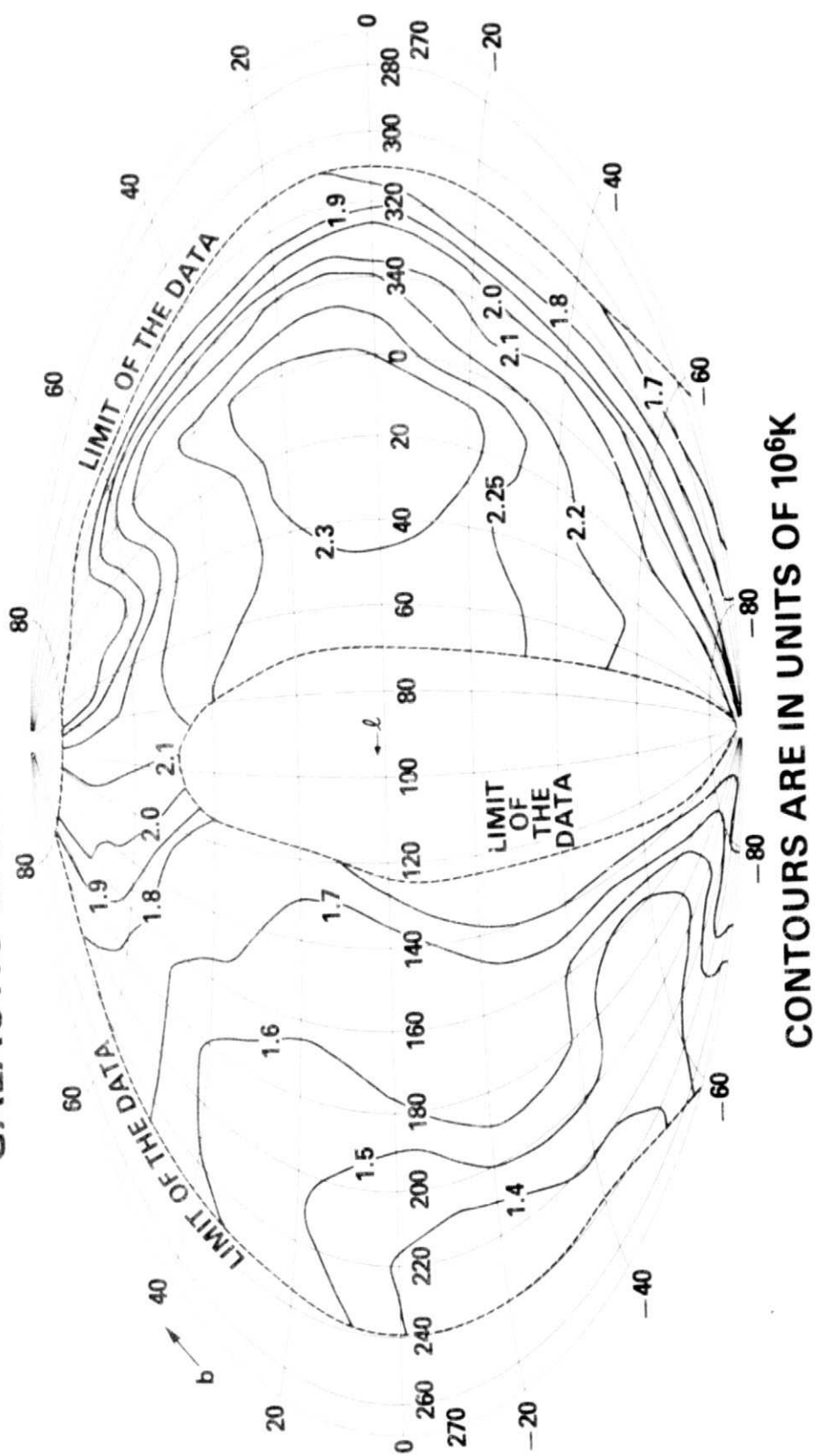
CONTOURS ARE IN UNITS OF 10^5 K

GALACTIC BACKGROUND AT 6.55 MHz

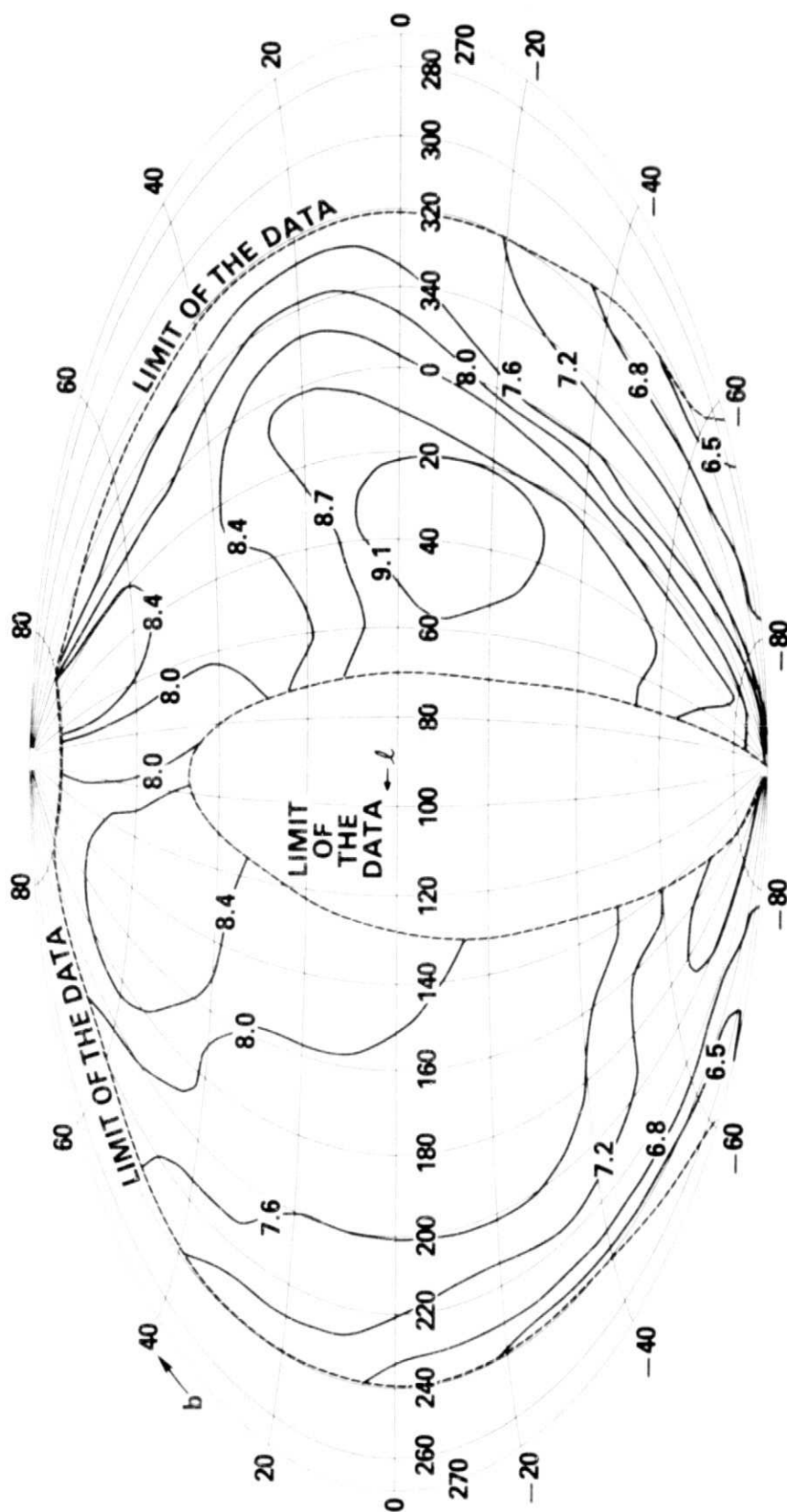


CONTOURS ARE IN UNITS OF $10^5 K$

GALACTIC BACKGROUND AT 4.70 MHz



GALACTIC BACKGROUND AT 2.2 MHz



CONTOURS ARE IN UNITS OF $10^6 K$

